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# Differences in Stimulus-Response Prediction and Reorientation of Attention Relative to Student Athletic Background

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Differences in Stimulus-Response Prediction and Reorientation of Attention Relative to Student

Athletic Background

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## **Introduction**

### ***Expertise in Sports***

Sports have been the mainstay of entertainment for centuries and will continue to be as long as the human population subsists. To most people, they are just that – entertainment. However, the athletes that we dedicate our time to watching have devoted their lives to their sport. Every minute detail throughout an average day of these athletes is tailored to best garner success in their respective games. To reach a level of professional success, though, most have been playing and perfecting their specialized skills since adolescents or earlier. As a kid, it is very common to play multiple different sports over the various seasons and slowly begin to specialize and attribute greater focus to one main sport as competition levels become more serious. To reach an expert level at any skill, there are a series of components that must be mastered in conjunction with each other. Prior to the development of skilled sport expertise comes the basic acquirement of the respective motor skills that will later determine level of athletic success.

At the most basic level of learning acquisition, Fitts and Posner (1967) proposed a still widely accepted theory of three stages of motor skill development: Cognitive, Associative, and Autonomous (Wulf, 2007). The initial cognitive stage begins the process by priming the learner to understand the fundamental requirements to perform the target skill and what the expected outcome should be (Wulf, 2007). The rudimentary nature of this stage requires a more conscious allocation of attention to carrying out the movement and is often performed more inefficiently at a much slower and more mechanical pace than the two subsequent stages, as is expected (Wulf, 2007; Fitts & Posner, 1967). The associative learning stage then develops as the learner becomes more consistent in the productivity of the motor skill and is able to start intuitively making

necessary adjustments to fine-tune performance (Wulf, 2007). Individuals now require less attentional focus on the physical movements as it starts to become a more consistent and automatic process (Wulf, 2007; Fitts & Posner, 1967). Finally, through extensive practice and continuous modifications, the final autonomous phase allows the learner to consistently and accurately perform the skill seemingly effortlessly, requiring little to no conscious attention towards conducting the movement as it has now become rather habitual (Wulf, 2007; Fitts & Posner, 1967). As the skill becomes more instinctive, the attentional and cognitive load lessens and the athlete can then begin working towards obtaining expert status in their sport as a whole.

Expert sport performance is characterized by a consistent and prolonged performance of superior athletic ability (Janelle & Hillman, 2003; Starkes, 1993). Janelle and Hillman (2007) posit that, following the acquisition of the simple motor skills, an athlete must then excel in four different facets of sports proficiency to obtain expert status: physiological, technical, cognitive, and emotional. The physiological component is interesting because it varies extensively between sports, even those requiring similar motor movements, and is also a facet of expertise that is mainly relevant only within the realm of sports. Specialists proficient in other fields do not yield the same necessity of honing precise respiratory control or developing and maintaining a specific body composition and physique, whereas the athletes best suited to do so are usually the most successful (Janelle & Hillman, 2003). Superiority in this physiological domain, however, also contains a genetic aspect, leaving an ambiguity of whether heredity or prolonged athletic training is the more influential factor behind which athletes are best suited to achieve the highest levels of success in their sport (Janelle & Hillman, 2003). The second expertise domain, technical expertise, expands further on Fitts and Posner's (1967) model of basic motor skill acquisition to encompass a refined and efficient implementation of the physical skills of a sport to yield

productive results due to considerably advanced degrees of sensorimotor coordination (Janelle & Hillman, 2003). The third component to becoming an expert in sport, though, is the most extensive and underestimated aptitude involved in overall athletic success, and is in this case the most pertinent to the ensuing body of work detailed throughout the remainder of this paper.

Beyond just attaining high levels of technical expertise, to truly exceed in a skilled sport, athletes must be entirely equipped to attribute additional training towards the cognitive components of their sport. It would be nearly impossible to succeed at the professional level of a sport without having perfected the necessary strategic and perceptual properties that influence the subsequent motor decisions. Janelle and Hillman's (2003) cognitive expertise domain entails two further sub-components respectively divided into refined tactical knowledge and decision-making skills, which are arguably the most underappreciated abilities required to attain desired levels of success. Tactile knowledge entails being able to choose the appropriate strategy within the specified physical restrictions of the sport to best respond to a given situation, while perceptual proficiency in sport expertise appears as the major area of interest with regard to this study (Janelle & Hillman, 2003). Open-skilled sports, such as those founded on complementary reactions to a series of events derived from a wide range of highly dynamic and unpredictable possible outcomes (Wang, et. al., 2013; Fontani, Lodi, Felici, Migliorini, & Corradeschi, 2006), require a greater aptitude for proper allocation of attentional resources than those with less external influence from the performance of opponent athletes or teams. Many of the most entertaining and highly regarded athletes have gotten there courtesy of enhanced cognitive abilities specifically honed over time to rapidly interpret significant perceptual information, utilize available predictive cues, and disregard irrelevant stimuli to all culminate into a split-

second game time decision regarding which strategic and motor response would be the most effective situational response (Janelle & Hillman, 2003).

The final expertise domain encompasses an athlete's ability to regulate and maintain emotional stability throughout a single game or entire season, while also developing psychological skills stringently tailored to focus on an individual's personal motivations, strategies, attitudes, and relational interactions guiding their pursuit success in their sport (Janelle & Hillman, 2003). Much of the recent sports psychology literature, though, has largely focused on examining the neural and behavioral factors involved in selectively allocating cognitive resources and how these factors and behavioral output vary between individuals across a high-to-low continuum of sports expertise.

Using the game of baseball as an example, the intricacies of the sport require a very particular repertoire of cognitive and technical skills to progress to the highest levels of competitive play. The functional composition of baseball, comprised of nine very specialized on-field positions and an intentionally strategic order of batters in a lineup, demonstrates the vast range of nuanced abilities the players must possess to best succeed in the complex sporting environment it fosters. What is often overlooked or unacknowledged within the game of baseball, though, is the outrageous magnitude of skill required to effectively perform the fine details of the desired motor response. The extreme accuracy, coordination, perceptual acuity, resiliency, and technical understanding found ubiquitously within every aspect of baseball are all equally essential in the modular, yet widely integrated, cognitive-motor processes responsible for producing an immediate and appropriate coordinative output in response to the given situation. The physical actions of hitting, pitching, catching, and throwing are all complex skills composed of smaller movements that form the basis of the technical expertise of baseball. However, one of

the most valuable skills that all athletes should perfect is the ability to selectively filter sensory information and critically evaluate predictive associations between the in-game expectations for the most likely trajectory of each impending play and the most appropriate strategic approach best suited to resolve the respectively predicted situation. The players that can most efficiently orient their attention to unexpected situations in their specific sporting environment are the athletes that achieve the highest levels of success and are best suited to continually adapt to the constantly progressing skill in athletics today.

While the current study examined a variety of student athletic backgrounds in relation to cognition, the hypotheses about the relationship between athletic skill and attention were developed based on the attentional requirements specifically within the game of baseball. Therefore, the following literature explores the perceptual components particular to baseball and softball attentional requirements more thoroughly than the other sports.

### ***Attentional Components of Baseball***

Rapidly shifting sensory information within a dynamically complex sporting environment rooted in spatial and temporal coordination is an extremely prominent and fundamental component of nearly all open-skill sports. As previously mentioned, the technical expertise required to reach the highest levels of competition is only one aspect of what allows the most skilled athletes to perform within their sport as effectively as they do. Continually progressing throughout the world of sports is almost always accompanied by an exponentially enhanced selectivity regarding the players chosen to fill the limited roster positions available. By the time these athletes reach professional status, discrepancies in physical ability typically are not distinct enough to blatantly favor one player over another. Underlying the advanced technicality

involved in sports expertise is the necessity of even greater cognitive abilities, which really end up being the true distinguishing factors used to disrupt an otherwise pretty equal playing field.

Players who possess a stronger proclivity to filter out distractions while attending to the relevant information present in their immediate visual field are consequently more adept at instinctively altering their behavioral response to follow their perceived optimal outcome (McAuliffe, 2004). The action of hitting a baseball encompasses two very functionally distinct requirements that players must effectively refine to be a productive batter, a status not all baseball players wield. Following the establishment of an effective hitting motion, typically composed of a forward shift of weight facilitating torso rotation to garner the most force for contact, baseball players also must be able to intuitively attune this motor coordination to the trajectory of the ensuing pitch (Katsumata, 2007). The twelve different potential pitches a batter could face vary widely on their respective flight paths and velocities, taking approximately 400-800 milliseconds (ms) to travel from the pitchers hand to home plate, of which at least 200 ms is required for the swinging motion alone (Katsumata, 2007). Prior to initiating a swing, a batter must first form an expectation based on situational context and nearly imperceptible cues given off by the pitcher and then analyze the relevant visual information provided by the incoming pitch to make an informed decision on how to engage in bat-to-ball contact.

The pitcher's entire goal behind each pitch is to disrupt the hitter's perceptual coordination enough to induce temporal and/or spatial errors in their swing to elicit a strike or out. Knowing this is often the case, batters still form predictions for the ensuing pitch type, but the most elite hitters in baseball are also the ones who are the best suited to properly modulate an incorrectly anticipated swinging motion in response to a different, unexpected pitch in a matter of milliseconds (Katsumata, 2007). Deception can be an extremely advantageous tool used to



provide misleading information to an opponent as an attempt to provoke a futile performance, and to overcome this, informative cues that appear salient must be intuitively either heeded or disregarded with the hopes of guiding the opposing party to produce an effective response (McAuliffe, 2004). The entire perceptual decision-making process behind a single swing has to be carried out within that 800ms window, which is why a propensity for allocating and reorienting attention guided by situational expectancies and visual cues is imperative within not only this single facet but the entire game of baseball as well, along with most other sports.

### *Exploration of Cognition in Sports*

The original scope of research surrounding sports proficiency used to focus solely on the physical scope of said expertise, however, recent literature now widely explores the cognitive component involved in expert athleticism relative to those of lower to no athletic ability (Furley & Wood, 2016). Attentionally demanding tasks omnipresent throughout sports can be simulated by commonly implemented experimental conditions, such as Posner's (1980) spatial cuing paradigm. Similar to the visual search and selective attention required to hit a baseball, spatial cuing tasks utilize an informative cue to facilitate or mislead the prediction of the probable location for the presentation of the subsequent target, eliciting the respective motor response from the participant (McAuliffe, 2004; Posner, 1980). The task conditions where the informative cue accurately indicates the location of the target are considered validly cued trials, while the less frequent instances where the cue provides erroneous spatial prompting are denoted as invalid trials. The cuing framework for this experimental technique is strongly embodied within the perceptual-cognitive attunement observed throughout the vast range of athletic proficiency. The comparability of the executive control requirements of the two allow for such spatial cuing tasks

to relatively analyze expectancy-guided attentional allocation and reorientation in a systematic setting rather than a highly variable in-game environment.

There are two different paradigms commonly used throughout psychological literature to explore sport-related differences in cognition. Differing in their approach, the first develops the experimental conditions to reflect a naturalistic environment akin to the specific sport of study, aptly deemed the *expert performance approach*, while the *cognitive component skills approach* removes the context of the sport by using systematically controlled measures of cognition to examine its respective relationship with sports expertise (Voss, Kramer, Basak, Prakash, & Roberts, 2010). The former perspective follows that expert athletes will outperform their less skilled counterparts on tasks relevant to the cognitive requirements of a realistic sporting environment and that this effect is exemplified almost solely within the perceptual realm of the sport (Voss, et. al., 2010; Mann, Williams, Ward, & Janelle, 2007). In contrast, the latter approach employs basic systematic tasks to explore differences in fundamental cognitive abilities, utilized in both the perceptual demands of the sport and in everyday activities, developed in part due to the advanced sport training (Voss, et. al., 2010).

Unsurprisingly, many expert performance approach-based studies demonstrate superior performance by the expert athletes on perceptual-cognitive skills relevant in their sporting environment and attribute the ability to overcome normal human processing constraints to the strategies acquired through persistent training that increases the efficiency of the perceptual decision-making processes unique to their field of expertise (Furley & Wood, 2016; Mann, et. al., 2007). However, evidence from visual cuing tasks across varying degrees of athletic skill consistently demonstrates a fundamental cognitive advantage in general for those with greater

sports experience than those without (Voss, et. al., 2010), as will be the main emphasis throughout this paper.

Open-skilled and interceptive sports are founded on highly irregular and dynamic conditions that necessitate split-second reactions to achieve the optimal outcome. These reactions are produced by a series of cognitive-motor processes initialized significantly prior to the response-eliciting event, beginning with the formation of situational expectations. The components behind this stimulus-response behavior can be replicated using attentional cuing paradigms in experimental settings. Through these, participants are provided informative cues to indicate the anticipated location or timing of the ensuing target stimulus and respectively instructed to respond as quickly and accurately as possible (Voss, et. al., 2010). Visual attention is then guided by the spatial or temporal cue to attend to the specified time or place of the target in preparation to respond (McAuliffe, 2004; Voss, et. al., 2010).

This phenomenon can be seen throughout sports as athletes must be able to incessantly anticipate the result of certain scenarios in order to facilitate their strategic plan of response. For example, volleyball players undergo extensive training to be able to identify and interpret task-relevant visual cues from players on both the opposing team and their own, as was much of the focus of my own volleyball training throughout high school. The setter's physical form and contact with the ball is used to indicate which offensive position to expect the resulting final hit from, while the hitter's approach and angle to the ball anticipates the trajectory of the ball and force of contact to expect the attack. With this visual information available, the players on the opposing side of the court are able to form expectations for the impending play and adjust their positioning and response strategy accordingly. However, misleading motions are often used to trick the other team into anticipating a false play and therefore initiating an incorrect and

unsuccessful response. The cognitive process used to guide this goal-oriented behavior, similar to that required to hit a baseball, relies on an efficient allocation of attentional resources towards relevant information and the rapid reorientation of attention when faced with an unexpected outcome.

There are several theories surrounding why athletes tend to possess a greater capacity for selectively attending to relevant stimuli while ignoring distractions. Those who follow the perspective of solely sport-specific advantages to expertise tend to maintain the position that the strategy and knowledge acquisition specific to their environment yields the precise perceptual advantages they require for their game (Nougier, Azemar, Stein, & Ripoll, 1992; Mann, et. al., 2007; Voss, et. al., 2010). In contrast, however, there seems to be a rather overwhelming consensus in recent literature that general cognitive advantages exhibited by expert athletes are likely due to a honed ability to efficiently allocate attentional resources to simultaneously enhance and suppress attention towards pertinent and irrelevant information respectively (Enns & Richards, 1997; Nougier, et. al., 1992; Voss, et. al., 2010). The discrepancies in these two perspectives appear to follow variations of the attentional system targeted and experimental design, separate from the disparities in the aforementioned sports-cognition foundational approaches.

Attentional cuing experiments allow researchers to measure differences in visual perception and response processes between different populations of varying athletic backgrounds. Further within this method, researchers can then vary the presentation and usefulness of the cue stimulus in relation to the target and response mechanism. A centrally located informative cue means that the cue commands foveal attention from the subject and provides some sort of informative context as to where or when one should likely expect the

response-eliciting target stimulus to appear (McAuliffe, 2004; Voss, et. al., 2010). Central, informative cues are used to measure components of voluntary orientating of attention as the subjects are able to actively decide whether or not to heed the information provided by the cue.

The study of voluntary covert attentional control best mimics the situational context often provided in sporting events that require rapid detection and interpretation of meaningful in-game signals to aid the decision-making process to evoke an appropriate response (Enns & Richards, 1997). One of the main insights from studies analyzing this attentional system has been the identification of a smaller cuing effect in expert athletes compared to groups with lesser to no athletic skill (Nougier, et. al., 1992; Enns & Richards, 1997; Voss, et. al., 2010). Athletes consistently demonstrated faster and more accurate responses than less-skilled subjects to targets preceded by an invalid, or incorrectly predictive, cue, while there were less substantial differences between groups of different skill levels on valid trials when the target location or timing were accurately predicted, therefore, leading to a smaller effect from the cue for the expert athletes (Nougier, et. al., 1992; Enns & Richards, 1997; Mann, et. al., 2007; Voss, et. al., 2010).

Enns and Richards (1997) developed a comprehensive two-fold spatial cuing study using non-athlete college students and low-skilled and high-skilled hockey players of ages 12 and 15 in an experiment utilizing a central informative cue and another using noninformative peripheral cues. The inclusion of two age groups for the two skill classes compared against older participants with no hockey skill allowed them to attribute the reduced orienting effect found in the central informative cue tasks to the advanced skill level rather than a developmental component of enhanced cognition (Enns & Richards, 1997). However, the peripheral noninformative cued trials necessitating automatic attentional orientation did not demonstrate the

same difference in the cuing effect, which strongly indicates that perception in sports maintains greater reliance on top-down attentional modulation as opposed to an immediate reflexive response (Enns & Richards, 1997). Their results corroborated Nougier et. al's (1992) previous conclusions and have also since been substantiated by recent meta-analytical reviews by Voss et. al (2010) and Mann et. al. (2007), all of which established that more advanced sport training and skill led to a greater efficiency of attentional orienting. Interestingly enough, following the pattern from the second portion of Enns and Richards (1997) experiment, McAuliffe (2004) used an similar spatial cuing paradigm of noninformative peripheral cues with collegiate volleyball players and control students to further explore involuntary attentional control and found no existence of a reduced cuing effect in the athletes in terms of attentional set capacity. Here they found that the athletes actually look longer than the non-athletes to disengage their attention from the location that they had identified as sharing some attribute with the erroneous cue, therefore interpreting the misleading information as informative and setting their attention to the anticipated location so as to ideally facilitate their response rate.

The different findings according to which attentional measures were employed indicates how overwhelmingly imperative the efficient allocation of cognitive resources is within the realm of sports expertise. The reduced cuing effect from relevant cues stems from the athletes' superior ability to adjust their expectations from what was prematurely gathered from the available visual information to the actual outcome of the play or task by rapidly reorienting their attention to the newly presented context. This seems to contrast McAuliffe's (2004) finding pertaining to attentional set but can actually be interpreted complementarily as the athletes were more attuned to recognize pertinent information within the cues and selectively attend to the targets that shared the appearance of task-relevance while ignoring others deemed distracting.

As persistent as these results are demonstrating that sports expertise tends to directly encompass enhanced mechanisms of selective attentional allocation, this relationship favors sports rooted in open skills and interceptive opponent interactions that require greater control, reactivity and flexibility in live-game situations rather than self-paced sports with limited time constraints allowing athletes ample time to execute their pre-determined and repetitively practiced routine (Singer, 2000; Voss, et. al., 2010). The preceding literature focuses on interceptive sports such as hockey, volleyball, tennis, basketball, and baseball that mainly rely on the actions of others in the game, regardless of opposing team or not, in order to make an informed decision and subsequent coordinative motor response. While some components of these sports (e.g. tennis or volleyball serve, basketball free throw, or pitch in baseball) are considered closed motor skills moderated by the individual, the most successful athletes in these fields have mastered their ability to selectively attend solely to valid perceptual stimuli relevant to their goal-oriented intentions necessary to overcome the inherently unpredictable and inconsistent framework of externally-paced sports.

### ***Neural Measures of Attention***

Throughout decades of research attempting to elucidate the neural correlates responsible for the production of the basic human facilities of sensation, perception, and thought development that collectively comprise the overarching notion of cognition, neuroscientists have been able to reliably identify underlying relationships between particular networks, regions, and wavelengths within the brain and their behavioral counterpart. Neuroimaging techniques, such as functional magnetic resonance imaging (fMRI), transcranial magnetic stimulation (TMS), and electroencephalography (EEG), are extremely effective methods used to isolate task-relevant neural activity, incur contained temporary lesions, and record electrical brain activity,

respectively, to explicate the corresponding brain and behavior associations. The complex neural processes implicated within visual and sensorimotor systems tend to respond the most fruitfully to the identification, manipulation, and isolation of relevant structural-functional connections due to the tangible nature of their particular cognitive outputs. However, it has proven slightly more challenging to determine the explicit modulatory mechanisms of action involved in systems of attention, as its resulting behavior is significantly less obvious and its regulation substantially more inadvertent. Because attention is guided by facets of vision, hearing, contextual knowledge, and informed decision-making, its successful deployment is in some way tethered to each of these complementary systems, making a modular distinction of attentional processes an inadequate representation of the system and the integrative nature of cognition.

Electrical measures of neural activity from EEG recordings are extremely useful at illustrating the various patterns of wavelength frequencies that are evoked in accordance to time-locked events presented within the experimental task conditions. Alpha frequency wavelengths (8-12 Hz) are found almost universally throughout the brain and the presence of alpha waves was originally associated with resting wakefulness, although now science has shown that alpha-band rhythms found within the occipital lobe differed amongst each other dependent on the presence of anticipatory timing information. Rhythms of the same wavelengths tend to remain similar in frequency, but can be externally or internally regulated to lag or lead in the phase of the neural oscillations compared to waves typically of the same frequency (Baars & Gage, 2013). The phase of a wave simply refers to the relative values of the wave continuously across one rhythmic period. Hence, phase difference between sinusoidal waves, as neural activity is, can be measured by lateral shifts in the onset times or the phase angle shift in degrees or radians between corresponding wave values at their respective zero reference points crossing the x-axis,



maximum amplitude peaks, or minimum trough values (Baars & Gage, 2013). EEG analyses of these desynchronized alpha-band phases, specifically within the occipital lobe, have been extremely effective at identifying a consistent shift in alpha-phase just prior to the expected target onset time when temporally predictive cues are present (Green & McDonald, 2010; Samaha, et. al., 2015). Researchers often also implement cuing paradigms to analyze voluntary orienting of attention guided by anticipatory cues regarding the probable location or timing of the target stimulus. The belief is that the pre-stimulus phase shift in alpha occurs as a result of the anticipatory information essentially guiding the visual cortex towards the suggested to-be-attended location in preparation to respond (Green & McDonald, 2010). Contralateral and ipsilateral alpha-band recordings have been analyzed to determine the explicit effect happening within alpha activity due to temporally predictive information guiding attention. When combined with spatial cues, increases in occipital alpha activity contralaterally to a cued location are believed to be enhancing the attentional focus towards the predicted location, while suppressed occipital alpha activity recorded ipsilaterally to the anticipated location is likely preventing attentional resources from being wasted on seemingly irrelevant details (Green & McDonald, 2010).

## **Methods**

The University of South Carolina Institutional Review Board approved all experimental procedures used in this study.

### ***Participants***

Thirteen undergraduate students (M= 5, F=8) from the University of South Carolina (USC) volunteered to participate in our study of attentional control. The college students ( $M_{age} = 19.6$  years,  $SD_{age} = 1.5$  years) voluntarily signed up to participate through the USC Psychology

Department's online undergraduate participant pool to receive extra credit in an applicable psychology course. Because the experimental motor responses depend first on dominant hand use and then the appropriate switching of hands, we also noted the handedness of each participant (right = 11, left = 2). Participants completed initial surveys and questionnaires pertaining to attention and learning abilities and individual athletic background. The sporting history questionnaire gathered de-identified general demographic information and data regarding each participant's history of involvement specifically in baseball or softball and then additionally their experience playing any and all other sports currently or while growing up. The questions (Appendix 1) addressed how many years they played, how many hours spent practicing per week, and the highest level of competition they achieved.

Between-subjects groups for analysis were designated according to which category the sport each participant played the longest fell under: baseball-specific, open-skill, or closed-skill. The baseball-specific group was composed of two males and three females who played either baseball or softball for the most years throughout their life ( $M_{years} = 10.6$ ,  $SD_{years} = 2.88$  yrs). The two left-handed participants were within the baseball group. The open-skill group was composed of three males, one of whom played basketball while the other two predominantly played soccer, and three females, two of whom played lacrosse the longest while the other played volleyball, ( $M_{years} = 6.83$ ,  $SD_{years} = 4.71$ ). These sports require fast-paced responses driven by externally guided and unpredictable actions of other players that entail the use of specific skills possible to attain the desired behavioral response within an open and dynamic setting, hence denoted 'open-skills'. The remaining two females fell into the closed-skill group with dominant sport experience within cheerleading and track/cross country ( $M_{years} = 6$ ,  $SD_{years} = 4$ ) that both allow for a greater degree of internal regulation within the sport and repetitively practiced precise

routines aimed towards consistency. Unfortunately, due to the limited number of observations, the two females in the closed-skill category were not included in the sporting group analyses between behavioral measures.

### ***Stimuli and Apparatus***

This study was conducted at The Institute for Mind and Brain within the EEG Suite. Each participant was allotted a two-hour time slot to complete the study, with the first hour to allow for surveys and EEG set up and the latter half dedicated to the completion of the experiment. Each trial (see Figure 1) presented a white central fixation cross in the middle of two 2” squares respectively on the left and right side of the screen. A colorful circular cue stimulus would then rapidly appear directly above the fixation cross as either cyan, magenta, or yellow. Within this cue, parallel lines and their corners were used to visually direct towards either the left or the right empty box on the screen. The target stimulus was presented as dark gray circle with horizontal bars of alternating shades of gray within it that would appear in either the square on the left or the right of the screen after a stimulus-onset asynchrony (SOA), or the time interval between cue onset and target onset, of 100 ms, 600 ms, or 900 ms. All participants responses to target onset were collected using both index-finger buttons on a console video game controller connected to the computer.

### ***Electrophysiological Recordings***

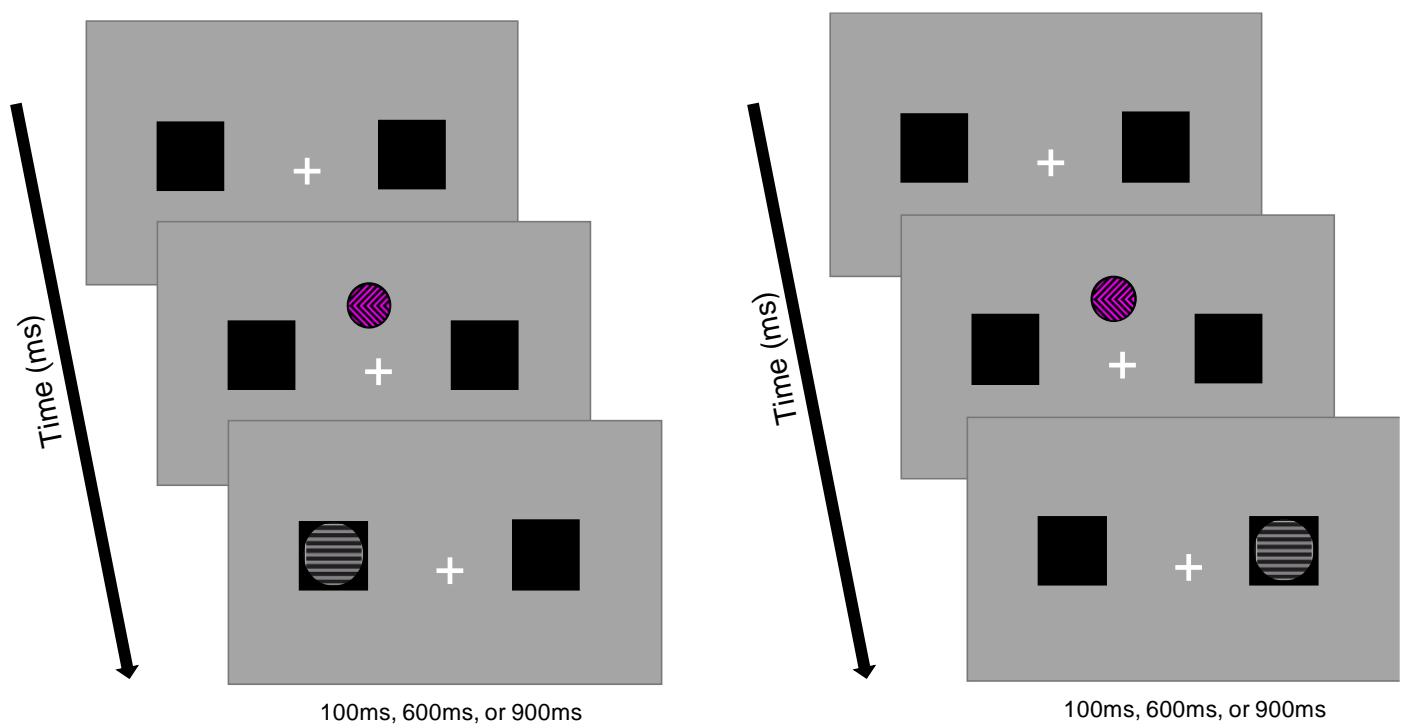
While participants sat at a standard wooden table and completed the initial surveys and questionnaires on the same black computer monitor that was to be used for the experiment. the 32-lead electrodes were configured into the properly sized elastic EEG cap,. Along with the 32 electrodes attached via the EEG cap, participants also had reference electrodes placed bilaterally on the mastoid bones behind their ears and horizontal electrooculogram (HEOG) electrodes

placed directly on either side of their eyes to gauge eye movement during the tasks. Once the electrodes were all reading properly through adequate saline gel application to aid conduction, a practice test of their first task was presented as the instructions for the three tasks were relayed.

### ***Procedure***

The experiment consisted of three tasks, each identical in the overall experimental design (Figure 1), but varying slightly between the instructed motor responses and the meaningfulness of the available predictive information. For each task, participants were instructed to respond to the appearance of the target stimulus using the game controller as quickly and accurately as they can and to use the information from the cues to assist in preparation for this response.

**Figure 1:** *Visual Illustration of Spatially Valid Trial (Left) and Spatially Invalid Trial (Right)*



**Figure 1:** With both trials depicting a leftwards facing cue, the left trial shows a spatially valid trial with the target location being accurately predicted while the right trial demonstrates a spatially invalid trial. Dependent on the counterbalanced SOA-color associations for task three, the color of the central cue would then also be either validly or invalidly predictive of the target onset time.

For task one and task two, subjects were told that the color of the cue was irrelevant, but that the direction of the arrows within it pointed towards the expected location for the target stimulus to appear, although accurate only 75% of the time. The targets in both of these tasks also appeared randomly across one of the three potential SOA time conditions of either short (100ms), medium (600ms), or long (900ms) onset time after cue. The response requirement of task one relied on a simple target detection response as they were told to respond to the presentation of the target stimulus with only their dominant hand regardless of which box it appeared in. Tasks two and three utilized a motor localization response where the participants had to discern which side of the screen the target appeared and respond with their respective hand on the game controller. The differentiation of motor response between task one and task two weights the cue for predicted target location as more pertinent in task two than one, so as to hopefully prime attention towards the correct location to help differentiate which hand to prepare to respond with.

Task three then attributed meaning towards the color of the initial cue stimulus. The subjects were told that the color of the cue now predicted one of the three SOA time conditions (short, medium, long) counterbalanced across participants and accurately predictive 75% of the time. For example, for one participant cyan would indicate a short SOA, magenta would indicate a medium SOA, and yellow would indicate a long SOA. The color of the cue was now a temporally predictive cue in conjunction with the spatially predictive direction of the arrows within it. Participants were told prior to beginning task three what their respective color-SOA associations were and to utilize the information about both the anticipated timing and probable location of the target to facilitate their ability to respond as quickly and accurately as possible.

### *Hypotheses*

In accordance with the evidence presented within the previous literature, we designed a progression of three tasks utilizing different levels of target location (left or right side), target onset time (100ms, 600ms, 900ms), task motor response (task one - only dominant hand response, task two and three – spatially localized hand response), and the validity of spatial and temporal cue (valid or invalid spatial cues in all three tasks; valid or invalid temporal cues only present in task three). In addition to these variable manipulations, the lengths of participant years of sporting experience allowed for an exploratory correlational analysis between extent of sporting experience and variations in the neural and behavioral data.

By varying the spatial and temporal predictability according to cue validity, our goal was to see how participant reaction times changed throughout the tasks dependent on the facilitation or misguidance of attention according to the available sensory information. Including neural data through EEG recordings, we also anticipated seeing within-subjects differences in the alpha phase shift dependent on the temporal predictability of each task (task one, task two, task three temporally valid, task three temporally invalid).

The complexity of these tasks yielded several hypotheses. First, we expected the spatially valid cues to yield significantly faster reaction times than spatially invalid cues between the first two tasks, with the first task also showing quicker overall reaction times due to the dominant-hand only response requirement. Second, we expected to see significant within-subject differences between the phase of alpha-band oscillations on temporally predictive trials than those lacking valid timing anticipations. Lastly, our hypotheses around sporting history first predicted that participants with the most baseball experience would exhibit quicker and more accurate responses to invalidly cued trials as an artifact of the requirements of their sport,

therefore yielding a smaller cueing effect. Also, we hypothesized that those with greater baseball and/or other general open-skill training to similarly have smaller phase differences in alpha between temporally valid and temporally invalid trials following theories of interceptive athletes being able to more efficiently allocate attentional resources thus yielding less overall phase differences.

### ***Data Analysis***

*Behavioral Measures.* Participant reaction times were measured and compared within subjects as a result of the various levels of the independent variables. Accuracy of trials was excluded as the tasks were simple enough to yield almost perfect response accuracy across and between subjects. The initial analysis conducted was a repeated measures ANOVA to show the within subjects effects of the task condition (task one detection, task two hand localization), the three possible cue-stimulus SOA's (short, medium, long), and the validity of the cued location (valid, invalid) on individual reaction times.

With the inclusion of both spatial and temporal cues in task three, an additional temporal cueing effect was calculated using individual reaction time differences between the two temporal validity levels on spatially invalid trials so as to best eliminate potentially confounding effects of predicted target location on reaction time differences. Holding the contrasting temporal cue condition invalid, a task three-specific spatial cueing effect was similarly calculated to yield two separate cueing effects on task three reaction times. Both of these respective task three cueing effects were compared to the task one and task two spatial cueing effects within the medium SOA factor in a one-way ANOVA to assess any significant differences between mean cueing effect varied by overall task conditions. The reaction times within temporally valid and invalid conditions throughout task three were then correlated to the years of dominant sports experience

to illustrate if any differences in reaction time were correlated with the length of sport-skill specific athletic training.

*Neural Measures.* In conjunction with the behavioral differences within groups, we were able to explore changes in the phase of alpha-band oscillations for each participant referenced against the variables in the experiment and correlated across athletic background. Alpha phase shifts in accordance to the temporal predictability of the ensuing target stimulus demonstrated how alpha wavelengths were modulated across the different temporal components of the tasks. Task one and task two trials lacked any cue towards anticipated timing, although still randomly varying SOA condition of target onset, while task three included valid and invalid temporal cues, producing four temporal cueing conditions used for alpha phase analysis. The short SOA of 100ms was excluded in alpha analysis as it was too short of a time period to significantly affect phase synchronization time-locked to an expected target.

A one-way ANOVA was then conducted to assess significant differences in alpha phase respective to the four temporal task components within the medium and long SOA. This analysis was done across both contralateral and ipsilateral electrode recordings for each SOA to explore associations between enhanced or suppressed attention and peak alpha activity. Following significance from these four ANOVA measures, paired t-tests for each permutation of available temporal cueing conditions further signified which task conditions yielded the significant differences in alpha phase as a result of target onset anticipation. We used the alpha phase data from electrodes PO7 and PO8, which were analytically designated as either contralateral or ipsilateral dependent on their spatial relationship to the expected target location for each trial. Associations between alpha activity respective to the to-be-attended location are used to suggest whether time-locked alpha phase shifts are actively enhancing or inhibiting selective attention.



We hypothesized that alpha phase would vary between type of athletic background according to validity of the temporal cue in task three. To explore this, we looked at correlations between the alpha phase on temporally valid trials, temporally invalid trials, and the valid-invalid phase difference for each sporting category still within the two electrodes for each SOA level.

## Results

### *Behavioral Results*

An analysis of variance between task condition (one, two), SOA (small, medium, large), and cue validity (valid, invalid) yielded several significant effects and interactions between the variables on within subject reaction times at the significance level of  $\alpha = 0.5$ . Task condition had a significant main effect on reaction times,  $F(1, 12) = 26.350, p < .001$ , such that task two response times were significantly greater than task one ( $MD = 15.24, SE = 2.970$ ). A significant main effect of cue validity was also determined,  $F(1, 12) = 55.236, p < .001$ , expectedly demonstrating significantly reduced reaction times for validly cued target locations than invalid ( $MD = -24.78, SD = 3.334$ ). The interaction between task and validity on participant reaction times was also significant,  $F(1,12) = 6.031, p = 0.030$ . Table 1 further depicts the significant simple main effects of the two cue validity levels (valid, invalid) on both task one and task two reaction times, while Figure 2 graphically illustrates these significant interactions.

**Table 1:** *Statistical Output of Cue Validity Simple Main Effects Within Task One and Two*

#### Simple Main Effects – Cue Validity ▼

Level of Task	Sum of Squares	df	Mean Square	F	p
Task 1	5517	1	5517	12.03	0.005
Task 2	20907	1	20907	54.31	< .001

*Note.* Type III Sum of Squares

**Table 1:** The above table demonstrates that the validity of the spatial cues significantly affected participant reaction times within both task one,  $F(1,12) = 12.03, p = 0.005$ , and task two,  $F(1, 12) = 54.31, p < .001$ , with the spatial cueing effect seen slightly stronger within task two.

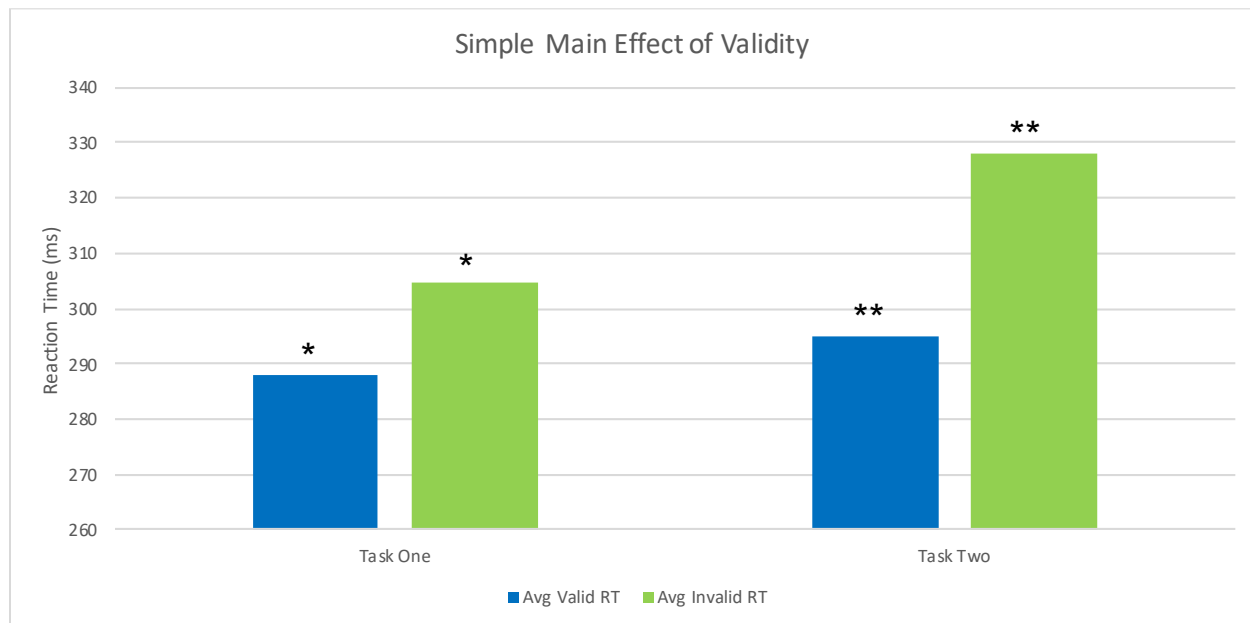
**Figure 2:** *Simple Effects of Cue Validity with both Validly and Invalidly Cued Trials***Figure 2:** Visual illustration of the significant differences in reaction times between spatially valid and invalid trials within task one and task two.\* $p = .005$ , \*\* $p < .001$ .

Table 2 inversely shows the simple effect the task response conditions between task one (dominant hand-only response) and task two (spatially localized hand response) had on reaction times for validly cued trials and invalidly cued trials across tasks; Figure 3 shows the graphical comparisons of the interaction.

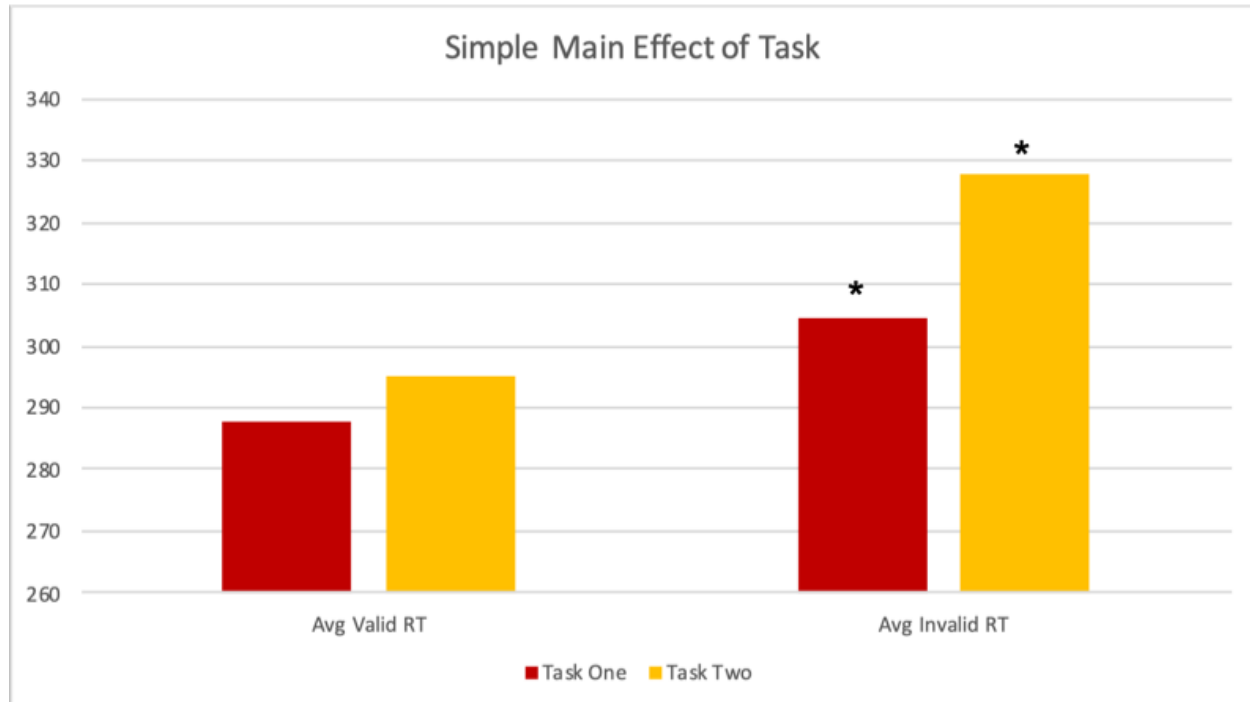
**Table 2:** *Statistical Output of Task Simple Main Effects within Each Validity Level*

## Simple Main Effects – Task

Level of Cue Validity	Sum of Squares	df	Mean Square	F	p
Valid	1034	1	1034	2.689	0.127
Invalid	10500	1	10500	28.440	< .001

Note. Type III Sum of Squares

**Table 2:** This table shows that participant reaction times differed significantly on invalidly cued trials from task one to task two,  $F(1, 12) = 28.440$ ,  $p < .001$ , whereas validly cued reaction times did not differ significantly between tasks,  $F(1, 12) = 2.689$ ,  $p = 0.127$ .

**Figure 3:** *Simple Effects of Task Condition on Validly and Invalidly Cued Reaction Times***Figure 2:** Graph visually depicting the significant difference of invalidly cued reaction times as an effect of the task response conditions of task one and task two.\* $p < .001$ .

These results demonstrate that participants were able to respond significantly faster to the presentation of the target stimulus when the preceding cue correctly predicted its ensuing location, rather than misleadingly, within both task conditions. Additionally, reaction times between tasks one and two significantly differed only across the invalidly cued trials in each task, while the addition of hand localization in task two did not significantly affect reaction times across spatially valid trials. The variation between the three levels of stimulus-onset asynchrony did not significantly affect or interact with the other variables on participant reaction times across the two tasks.

A separate repeated measures analysis of variance was done on task three reaction times to assess differences due to SOA, spatial cue validity, and temporal cue validity. There were no significant main effects due solely to a single variable, spatial validity was approaching

significance,  $F(1, 12) = 3.76$ ,  $p = 0.076$ , but there were two significant interactions shown to modulate participant reaction times. First, SOA length and spatial cue validity showed a significant interaction, with spatially accurate predictions eliciting significantly faster reaction times than spatially invalid trials only within long SOA conditions,  $F(1, 12) = 21.962$ ,  $p < .001$ , although this effect nears significance within medium SOA trials,  $F(1) = 3.773$ ,  $p = 0.076$ . Spatially invalid trial response times also significantly differed between the three SOA conditions,  $F(1) = 9.717$ ,  $p < .001$ , while the accurately predictive trial times did not. The spatial validity and temporal validity interaction, however, had the most significant effect on participant reaction times,  $F(1, 12) = 9.156$ ,  $p = 0.011$ . Table 3 below breaks down the significant effect of spatial validity on reaction times within temporally invalid trials, followed by a visual comparison of the mean differences (Figure 4).

**Table 3:** *Statistical Output of Spatial Validity Main Effects within Each Temporal Validity*

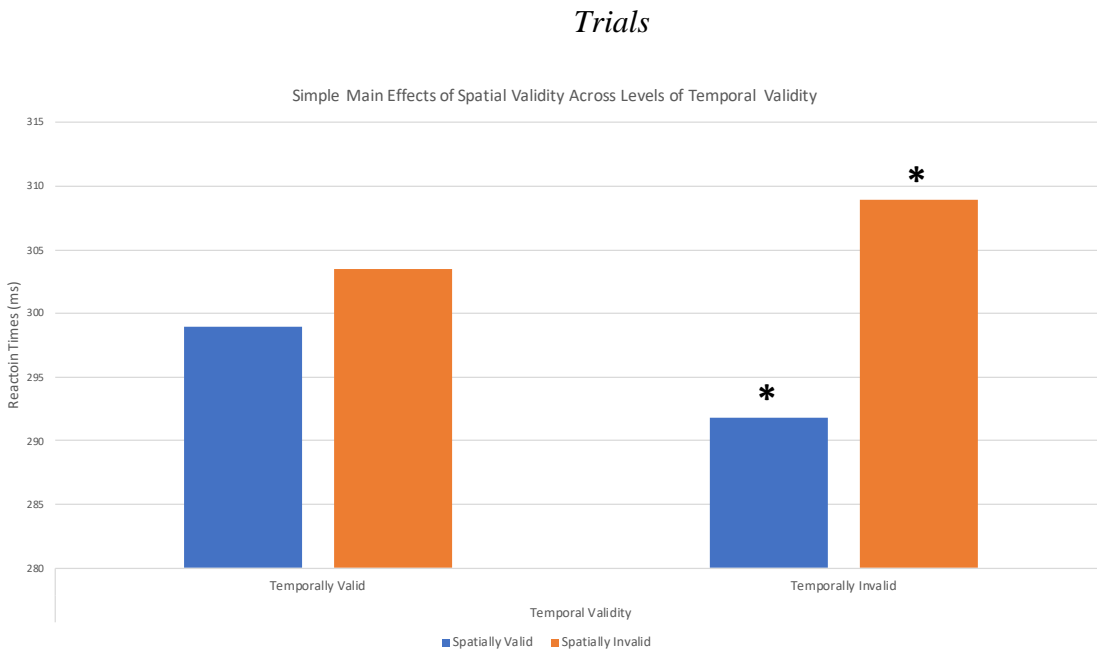
*Condition in Task Three*

Simple Main Effects – Spatial Cue Validity ▼

Level of Temporal Cue Validity	Sum of Squares	df	Mean Square	F	p
Valid	397.1	1	397.1	0.505	0.491
Invalid	5746.5	1	5746.5	9.528	0.009

Note. Type III Sum of Squares

**Table 3:** This table shows how reaction times significantly differed dependent on spatial validity within temporally invalid trials,  $F(1, 12) = 9.528$ ,  $p = 0.009$ , but the levels of spatial validity did not significantly affect reaction times across the two conditions when mutually paired with temporally predictive cues,  $F(1, 12) = 9.528$ ,  $p = 0.009$ .

**Figure 4:** *Task Three Simple Effects of Spatial Validity within Temporally Valid and Invalid***Figure 4:** This graph visually compares mean reaction time differences between spatially valid and invalid trials when presented with either a temporally valid or invalid cue.\* $p = 0.009$ 

Consistently, Table 4 shows that the simple effect of temporal validity was only significant within spatially invalid trials,  $F(1, 12) = 6.817$ ,  $p = 0.023$ , although was nearly significant within valid spatial trials as well,  $F(1, 12) = 4.687$ ,  $p = 0.051$ . Figure 5 provides an illustration of the significant interactions and the directionality of the effects.

**Table 4:** *Statistical Output of Temporal Validity Main Effects within Each Spatial Validity**Condition in Task Three*

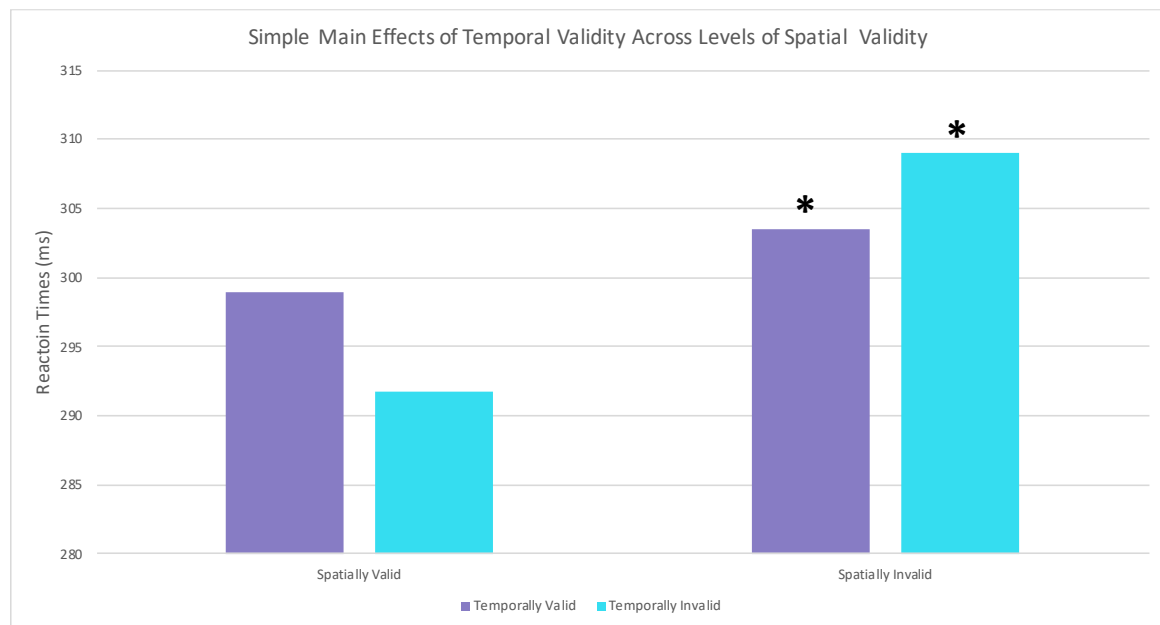
Simple Main Effects – Temporal Cue Validity

Level of Spatial Cue Validity	Sum of Squares	df	Mean Square	F	p
Valid	1005.1	1	1005.1	4.687	0.051
Invalid	584.4	1	584.4	6.817	0.023

Note. Type III Sum of Squares

**Table 4:** Statistical output showing the significant effect of temporal validity within spatially invalid trials,  $F(1, 12) = 6.817$ ,  $p = 0.023$ , while also nearly significant within spatially valid trials,  $F(1, 12) = 4.687$ ,  $p = 0.051$ .

**Figure 5:** *Task Three Simple Effects of Temporal Validity within Spatially Valid and Invalid Trials*



**Figure 5:** Illustration of the mean reaction time differences between temporally valid and invalid trials within both spatially valid and spatially invalid trials. Interestingly, although the temporal validity effect was not wholly significant within spatially valid trials, the graph demonstrates that the effect from the two levels of temporal validity differed in the directionality of the effect on reaction times.

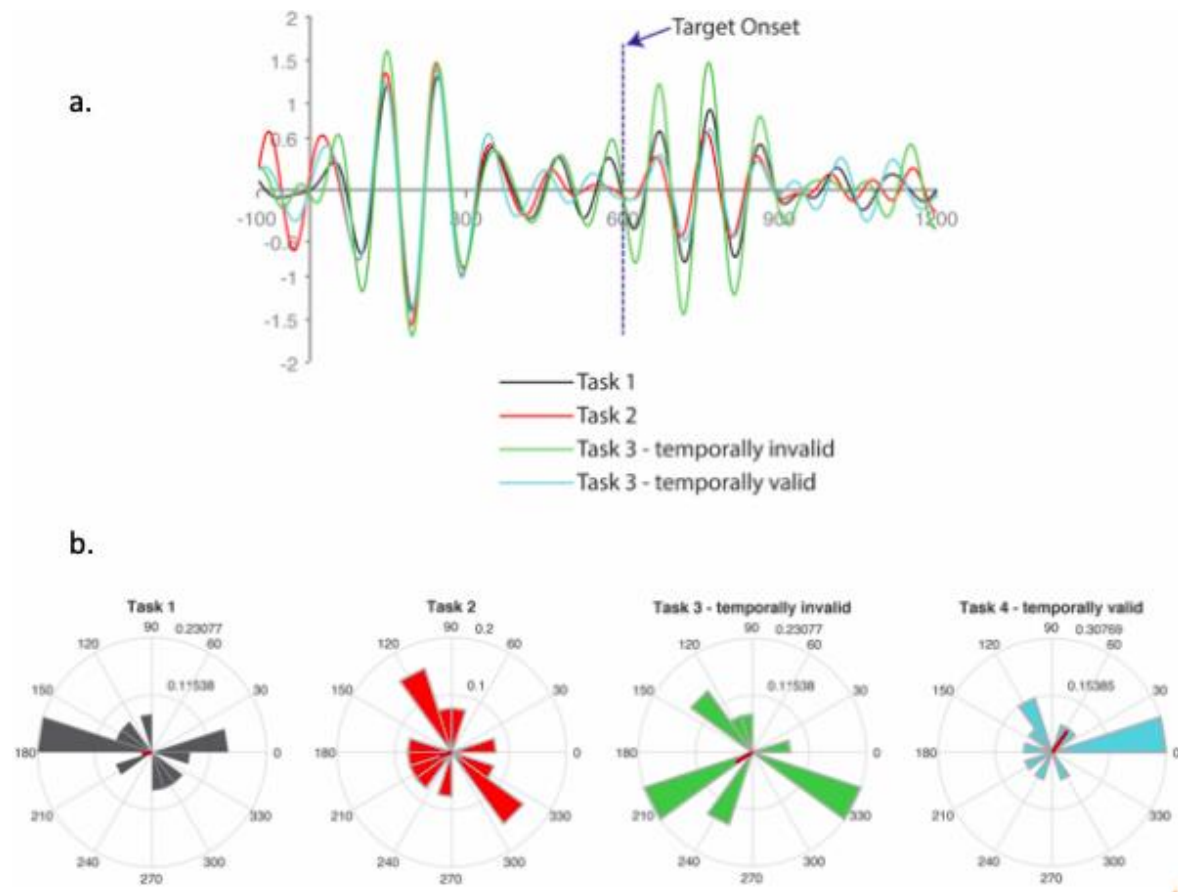
\* $p = 0.023$ .

The above results demonstrate that invalid spatial cues did not elicit significantly longer reaction times than valid spatial cues when presented in conjunction with valid temporal cues, thus suggesting the degree of the spatial cueing effect could have potentially been mitigated by the formation of correct temporal anticipations used to guide preparation to respond. This interpretation becomes a little more complicated by the graphical depiction of the temporal validity simple effects (Figure 5). The longer reaction times to temporally valid cues than temporally invalid cues within spatially valid trials seems to contrast expectations that two validly anticipatory cues would elicit the shortest reaction times across participants, of which the opposite is seen here. While there were significant differences between valid and invalid cue reaction times within subjects, the one-way ANOVA conducted between all four cueing effects

(task one spatial, task two spatial, task three spatial, and task three temporal) did not yield significant differences,  $F(3, 48) = 1.921, p = 0.139$ .

### ***Neural Results***

In addition to the behavioral data from factor manipulation, the various cueing effects were also analyzed across the neural alpha phase data, excluding short SOA measures, and then correlated across participant maximum years of skill-based athletic experience. The first one-way ANOVA was conducted to determine contralateral alpha phase differences between the four temporal cueing conditions (task one- no temporal, task two- no temporal, task three- valid temporal, and task three- invalid temporal) time-locked to the medium SOA of 600 ms. This yielded a significant effect of the temporality of the task condition on the pre-stimulus alpha-band phase,  $F(3, 48) = 4.05, p = 0.12$  (Figure 6). Paired t-tests then revealed which specific task temporality conditions significantly differed from one another in their respective modulations of alpha-band oscillations within the medium SOA (Figure 7a). Task three temporally valid trials evoked a significantly different pre-stimulus alpha-band phase than not only task one,  $t = 2.09, p = 0.047$ , but also task two,  $t = 2.57, p = 0.017$ , both of which contain no temporal indications, and task three invalid temporal trials,  $t = 2.95, p = 0.007$ . These significant differences comprehensively support the widely accepted conclusion that occipital alpha-band oscillations are preemptively modulated the availability of temporal anticipatory information, showing that the voluntary orientation of attention through temporal cueing does significantly affect how alpha-band dynamics shift and differ immediately prior to stimulus onset in an effort to best facilitate the production of the desired response on such goal-oriented tasks.

**Figure 6:** Temporally Modulated Alpha-band Oscillation Shifts and Phase Plots in Med SOA

**Figure 6:** (a) Visual depiction of the differences in the EEG averaged activity of alpha-band oscillations across the four temporal task conditions within the medium SOA condition. Here, the light blue wave can be seen to cross the x-axis immediately prior to the expected 600 ms onset time and earlier than seen in the other three temporal variations, thus showing the significant pre-stimulus phase shift evoked by the valid temporal prediction. (b) Phasic graphs illustrating the varying phase angles modulated by each temporal condition, with the small red line stemming out from the center representing the average phase angle within each task.

The phasic graphs in Figure 6 (b) illustrates how the average alpha phase angle, or degree of alpha phase shift within each task, is within generally the same range of phase angle for the first three temporal task conditions and almost completely opposite than the task three temporally valid average phase angle.

With this significant effect of expected timing on the modulation of alpha phase shifts, Pearson correlations (Figure 7b) then showed if there were any significant correlations between the number of years participants played their longest sport and the degree of the alpha-band



phase shifts seen within both task three temporally valid and invalid trials and the phase difference between the two still within the medium SOA.

**Figure 7:** Differences in Alpha Phase Shifts by Task Temporality as Related to Sporting History

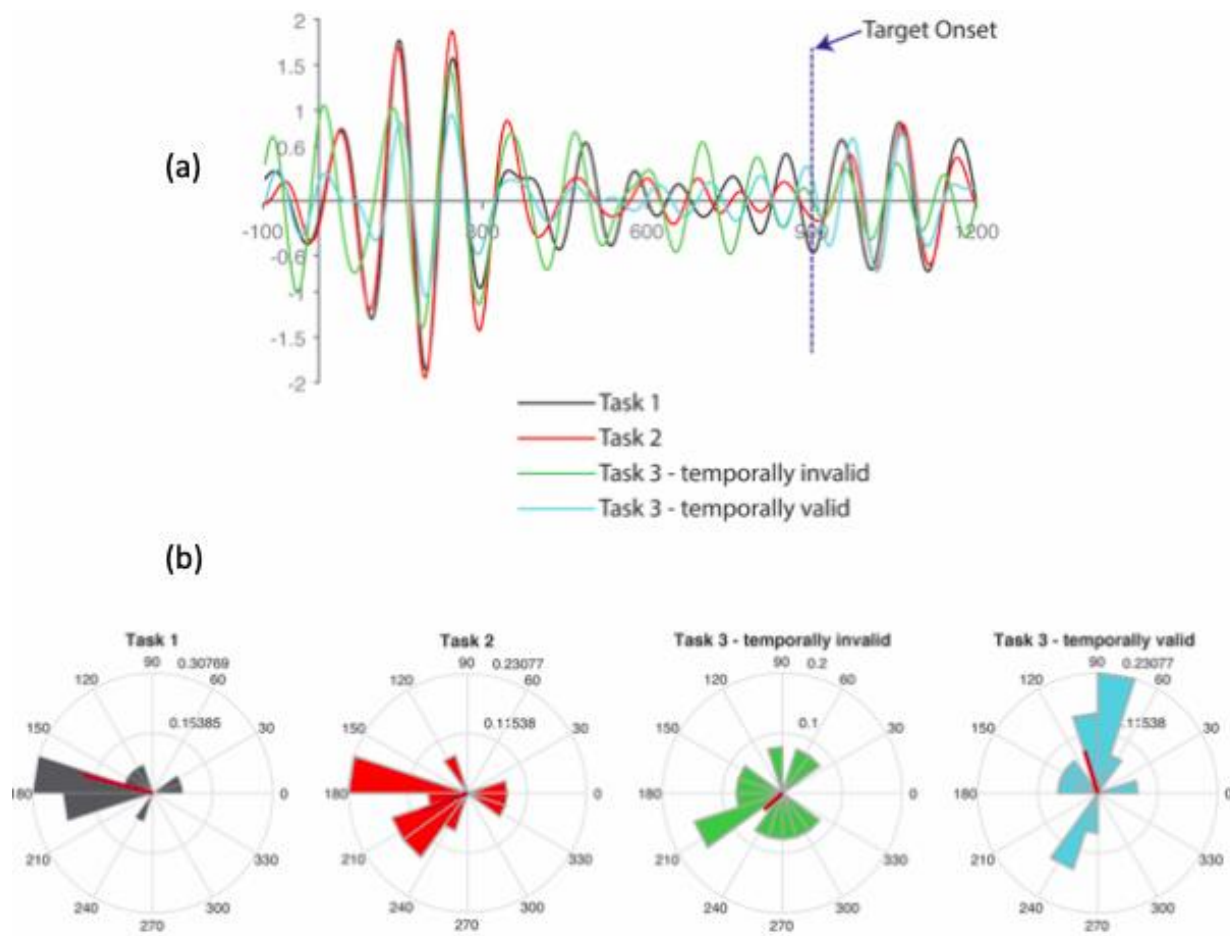
Medium SOA - contralateral			
1-way ANOVA		F(3,48)=4.05, p=.012	
		t-stat	p-value
(a)	Task 1 vs Task 2	0.13	0.897
	Task 1 vs Task 3-invalid	0.38	0.710
	Task 1 vs Task 3-valid	2.09	0.047
	Task 2 vs Task 3-invalid	0.27	0.789
	Task 2 vs Task 3-valid	2.57	0.017
	Task 3-invalid vs. Task 3-valid	2.95	0.007
		r	p-value
(b)	task3-valid baseball	0.76	0.02
	task3-valid max open	0.65	0.06
	task3-valid max closed	0.42	0.32
	task3-invalid baseball	0.27	0.62
	task3-invalid max open	0.07	0.97
	task3-invalid max closed	0.22	0.73
	valid-invalid baseball	0.73	0.03
	valid-invalid max open	0.45	0.27
	valid-invalid max closed	0.28	0.61
Significance Key:		Significant Difference or Correlation	
		No Significant Relationship	

**Figure 7:** (a) The paired t-test comparisons highlighted in red isolate the three comparisons of temporal task conditions that yielded significant phase differences between alpha oscillations modulated respectively by presence of temporal guidance. (b) The three relationships highlighted in red in the lower section show the significant positive correlations present between longevity of both baseball and open-skill sport experience and the degree of alpha modulation seen within task three valid temporal trials, while the extent of the valid-invalid phase difference in task three was only directly related to the years of baseball experience.

As seen in Figure 7(b) above, the degree of alpha phase modulations within task three valid temporal trials and years of experience of participants with baseball-dominant backgrounds were directly correlated,  $r = 0.76$ ,  $p = 0.02$ , suggesting that the magnitude of the phase differential seen in task three valid trials increases as the years of baseball-specific experience increase. Similarly, task three valid alpha shifts were positively correlated with years of general open-skill sport experience,  $r = 0.65$ ,  $p = 0.06$ . A significant correlation was also present between the task three phase difference between valid and invalid trials and years of baseball experience,  $r = 0.73$ ,

$p = 0.03$ . Significant data from the ipsilateral electrode one-way ANOVA for alpha phase in the medium SOA,  $F(3,48) = 2.83$ ,  $p = 0.048$ , mirrored the significance of the temporal condition comparisons showing significant alpha phase differences between task three valid trials and task one,  $t = 2.74$ ,  $p = 0.011$ , task two,  $t = 2.50$ ,  $p = 0.020$ , and task three invalid trials,  $t = 2.15$ ,  $p = 0.042$ . However, neither analysis of the two ipsilateral alpha recordings at the medium or the long SOA demonstrated significant correlations with athletic experience.

The trends of these relationships found within the medium SOA were nearly replicated within the long SOA contralateral alpha phase analyses (Figure 8), with only a few lesser degrees of significance. The overall significant one-way ANOVA for the contralateral recordings,  $F(3, 48) = 3.54$ ,  $p = 0.021$  (Figure 9a), further broke down to demonstrate significantly different shifts of alpha phase between task two and task three temporally valid,  $t = 2.66$ ,  $p = 0.014$ , and task three temporally invalid and valid trials,  $t = 2.80$ ,  $p = 0.10$ . The difference between alpha in task one and task three valid that was previously significant was not significant in the long SOA,  $t = 1.91$ ,  $p = 0.68$ . These effects can be observed in the slight variations in the time each temporal condition's respective alpha waves cross the x-axis reference at different time points than when previously rather synchronized illustrated below in Figure 8.

**Figure 8:** Temporally Modulated Alpha-band Oscillation Shifts and Phase Plots in Long SOA

**Figure 8:** (a) Visual depiction of the differences in the EEG averaged activity of alpha-band oscillations across the four temporal task conditions within the long SOA condition. (b) Phasic graphs illustrating the varying phase angles modulated by each temporal condition, with the small red line stemming out from the center representing the average phase angle within each task.

The only significant correlation between years of sporting history and task three temporal modulation of alpha (Figure 9b) was found within the task three temporally valid trials for open-skilled players,  $r = 0.71$ ,  $p = 0.036$ .

**Figure 9:** Differences in Alpha Phase Shifts by Task Temporality as Related to Sporting History

(a)

Long SOA - contralateral			
1-way ANOVA		F(3,48)=3.54, p=.021	
		t-stat	p-value
Task 1 vs Task 2		1.25	0.224
Task 1 vs Task 3-invalid		1.63	0.117
Task 1 vs Task 3-valid		1.91	0.068
Task 2 vs Task 3-invalid		1.75	0.585
Task 2 vs Task 3-valid		2.66	0.014
Task 3-invalid vs. Task 3-valid		2.80	0.010
		r	p-value
task3-valid	baseball	0.54	0.151
task3-valid	max open	0.71	0.036
task3-valid	max closed	0.32	0.507
task3-invalid	baseball	0.32	0.520
task3-invalid	max open	0.21	0.747
task3-invalid	max closed	0.12	0.916
valid-invalid	baseball	0.52	0.167
valid-invalid	max open	0.30	0.565
valid-invalid	max closed	0.32	0.519

(b)

Significance Key:		Significant Difference or Correlation	
		No Significant Relationship	
		Previously Significant, but Not Currently Significant	

**Figure 9:** (a) The long SOA paired t-test comparisons notated in red highlight the two paired comparisons of task temporal predictability that yielded significant phase differences within alpha oscillations modulated respectively by presence of temporal guidance, specifically between task three temporally valid trials and both task two trials and task three temporally invalid trials, independently. (b) The single relationship highlighted in red in the lower section shows the persistence of the significant positive correlation between longevity of open-skill sport experience and the degree of alpha modulation seen within task three valid temporal trials.

The long SOA contralateral correlations between baseball-dominance and task three valid phase,  $r = 0.54$ ,  $p = 0.151$ , and valid-invalid phase difference and baseball experience,  $r = 0.52$ ,  $p = 0.167$ , were not significantly correlated as found previously but were trending towards significance. The ipsilateral long SOA ANOVA was also generally significant,  $F(3, 48) = 2.97$ ,  $p = 0.041$ , resulting from significant alpha phase shift differences between the temporally invalid and temporally valid trials within task three,  $t = 2.52$ ,  $p = 0.019$ . The variations between the temporal task components and alpha phase here follow some of the patterns found within the

medium SOA to show how the attentional expectation of timing can evidently be seen to evoke a preemptive shift in alpha-band phase towards its optimal phase for target processing when compared to the tasks with misleading or completely lacking temporal cues.

Using the same metrics of years of dominant sporting experience, Pearson's correlation tests were conducted to determine if the reaction time lengths within both temporally valid and invalid trials in task three demonstrated any correlative relationships with sporting experience akin to the previous patterns of neural activity and sporting correlations. Of the eight correlations conducted separately between valid and invalid reaction times and years of experience for baseball-dominant and open-skill participants within the both medium and long SOA, the only significant correlation (Figure 10) was found positively between years of baseball experience and reaction times to task three invalid temporal cues in the medium SOA,  $r = 0.90$ ,  $t(3 \text{ df}) = 3.67$ ,  $p = 0.035$ , which can be seen clearly in the exploratory scatter plot of the relationship (Figure 11).

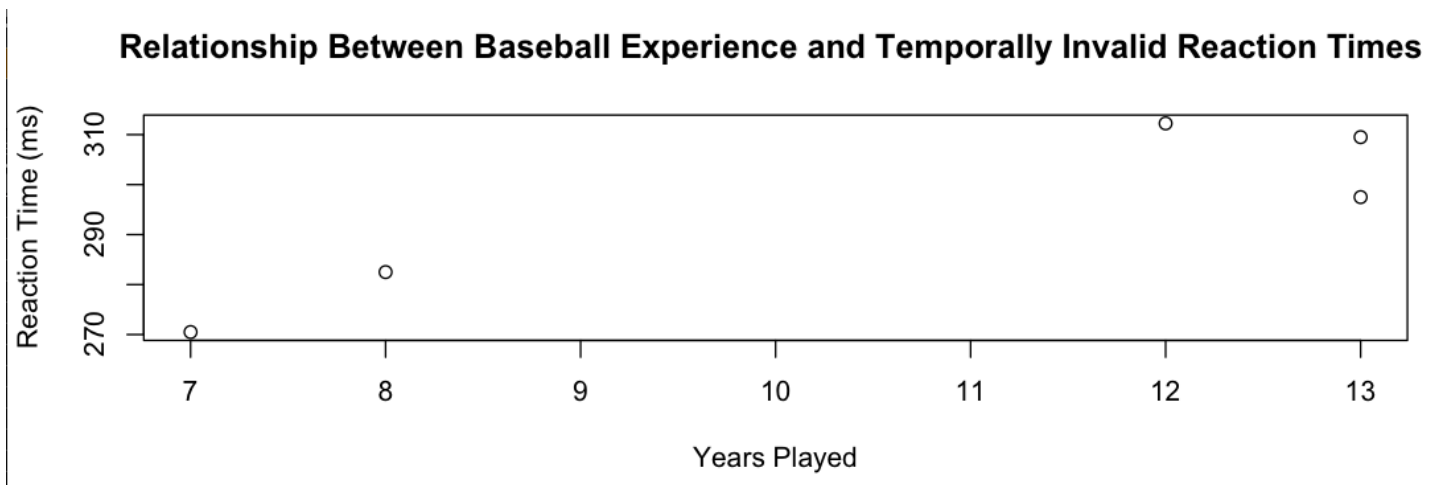
**Figure 10:** *Correlation between Baseball Experience and Temporally Invalid Reaction Times*

```
> cor.test(bb_years, bb_inval_temp_med)

Pearson's product-moment correlation

data: bb_years and bb_inval_temp_med
t = 3.6725, df = 3, p-value = 0.03494
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 0.1098235 0.9937435
sample estimates:
      cor
0.9044541
```

**Figure 10:** R analysis output for the Pearson's correlation test between the number of years of baseball experience for participants within the baseball-specific group and their reaction times for all temporally invalid trials throughout task three. The results indicate the level of significance within the relationship and a rather wide, yet significant, 95% confidence interval estimating the true correlation to be between 0.1098 and 0.994.

**Figure 11:** *Scatter Plot of Task Three Medium SOA Invalid Reaction Times against Baseball**Experience*

**Figure 11:** Visual illustration of the very preliminary positive relationship between baseball experience and reaction times on temporally invalid trials in task three for the medium SOA. According to this analysis, as the years of baseball experience increase, the reaction times to temporally invalid trials also increased.

## Discussion

The behavioral data for the most part confirmed our expectations of reaction time changes in accordance to manipulations between the various factor levels. Our first hypotheses of expecting valid spatial cues to yield faster reaction times overall and for task one to also report shorter response times were supported by the first repeated measures ANOVA. This showed that the guiding of attention towards the expected target location effectively prepared participants to respond quicker when the target finally appeared. Also, task two required participants to be able to first detect the presence of the target and then additionally discern which side of the screen it was on so as to respond with the corresponding hand. This spatial discernment and motor localization is not a complex coordination, but the additional recognition requirement in task two was enough to significantly increase participants reaction times between the two tasks. This is also corroborated by invalid reaction times significantly differing between tasks one and two but

the valid responses not. Attentional orientation towards the wrong potential target location in task one is much easier to overcome due to its stable motor response requiring no additional attentional control.

The comparisons of task three cueing effects showed spatial validity as having a greater cueing effect for the long SOA of 900ms and was near significance for the medium SOA of 600ms, too. I would imagine this discrepancy is due to longer grace period of time to interpret the task-relevant information from the cue and subsequently attune attention accordingly. It is reasonably likely that the addition of more participants would yield a significant spatial cueing effect within the medium SOA as well. More interestingly, though, it appeared that the spatial cues had a much greater effect on cueing attention than the temporal cues did within task three, corroborated by the near significant main effect of spatial validity. I would imagine this is probably due to a stronger affinity to interpret predictive information as meaningful when the cues and the target stimuli share perceptual characteristics, such that the visually displayed direction of the central cue arrows could more inherently be associated as anticipating the target location on the screen that is also visually displayed. The cues indicating towards a physically present entity on the screen, i.e. one of two potential squares the target could appear in, were more easily heeded by the participants and thus use to guide their output responses. While the colors of the cue-SOA associations were still presented visually on the screen, they represented the anticipation towards an abstract concept of timing, which people tend to have a weaker grasp on how long specific times actually feel. Asking people to predict one of two possible physically identifiable locations is logically a more tangible ability than attempting to anticipate a more unfamiliar construct of three potential time intervals. This then begs further analysis, though, to determine if the spatial cueing effect was significant due to its simple facilitation of reaction

times solely on valid trials or because people were more tangibly able to abide by the visual cue to set their attention stronger and were therefore less able to re-orient it when incorrectly cued.

The most intriguing results and implications, though, stemmed from the neural data. It was immediately apparent that while the temporal predictability may not overwhelmingly alter behavioral responses, it does in fact lead to biases of alpha phase in preparation for a response. This was significantly demonstrated throughout the consistent differences seen between tasks one, two, and temporally invalid task three alpha activity, all of which lack a component of temporal predictability, and the alpha phases seen in task three temporally invalid trials. A valid temporal cue preemptively guides alpha-band oscillations to prematurely shift the onset times of their maximum, minimum and reference values to occur just immediately prior to the anticipated target onset time and shifting out of synch with the other three task temporal alpha recordings. When alpha waves, with the same inherent frequency, cross from positive values to negative values at different times, they are said to be out of phase with each other. These temporally-guided alpha-band phase differences found occipitally in the hemisphere contralateral to the expected location have thoroughly been concluded as the alpha waveform being temporally guided to proactively shift towards its optimal phase for visual discrimination and processing, thus enhancing the allocation of attentional resources towards the predicted location and exhibiting peaks in alpha frequency at the cued onset time to facilitate the response (Green & McDonald, 2010).

The athletic correlations with alpha phase during temporally valid task three trials suggest that the years playing both baseball and open-skilled sports did significantly correlate with greater phase shift of alpha towards this optimal processing phase in response to valid temporal cues, with the open-skilled players showing this significant shift in both the medium and long



SOA contralateral activity, which actually contrasts my initial expectations. These correlations do not appear to follow much of the general literature consensus of sports expertise cognition, as I reasoned that the increasing degree of skill acquired through years of practice would yield greater attentional control and general perceptual advantages that would in turn suggest the athletes would show smaller phase differences in alpha as a response (Mann, et. al., 2007; Voss, et. al., 2010). This slightly unanticipated finding was also shown in the years playing baseball directly related to a greater phase difference in alpha between the temporally valid and invalid trials in task three medium SOA trials only, similarly demonstrating that the participants with the most baseball experience elicited the greatest shifts in alpha-phase between temporally valid and invalid trials in task three.

The persistence of the alpha-phase shift and open-skill sport experience correlation across both medium and long SOA conditions could be related to the variations in the necessary attentional set and scope of awareness across different sports. As most other open-skill sports besides baseball contain continuous motion across an entire field or court, like hockey and volleyball, athletes skilled at these sports must readily be able to perceive the actions occurring in their direct field of vision regarding the motion of the ball or puck, while also maintaining peripheral awareness of the ongoing and potential movements of the additional players in the surrounding fields of action. I would expect this to be a logical possibility for the reason the phase difference stays correlated only with open-skill experience across both the medium and long SOA conditions –the broader scope of attention inherent in these sports, especially related to training longevity, could consequently require a stronger pre-stimulus shift in alpha-phase so as to attempt to overcome any potential perceptual shortcomings present during the centrally-focused process of achieving the desired response.

The perceptual nature of baseball quite differs from these fast-paced sports, although both classified as externally-paced interceptive sports, such that the bulk of the unpredictable and rapid actions occur rather centrally in a player's field of vision, requiring less of a need to maintain peripheral awareness and perhaps a few possible interpretations of these results. Although the temporally valid phase difference is significantly correlated with baseball experience in the medium SOA, the lack of significance within the long SOA does suggest that just the 300ms increase in target onset time was enough time to essentially eliminate the size differentiation between the temporally valid alpha phase as directly related to extent of baseball history.

What was also intriguing was how the only significant correlation between years of athletic experience and the different task three temporal validity reaction times was between the baseball players experience and temporally invalid cues. These results suggest that the longer the participants played baseball, the longer they took to response to temporally invalid trials, which partially contrasts on of our hypotheses that the participants with the most baseball experience would respond faster to invalid cues than the other sporting groups, which we see is not the case here. Some sport literature suggests that the slightly less common yet still prevalent finding of a greater cueing effect in more highly skilled athletes could be due to these athletes more rigidly setting their attention according to their anticipated outcome conditions, and when the outcome is an unexpected one, they have a harder time rapidly disengaging from the erroneously attended-to expectations (McAuliffe, 2004). However, it is also extremely possible that these differences and relationships could be seen very differently with the inclusion of more participants and data. The nature of the physical motor response and overall design of the tasks could have also been too simplistic to truly simulate the practical application and interpretations of the vastly possible

outcomes within an actual in-game environment. In this case, a more comprehensive and specific experimental design would be necessary to truly encapsulate the extent of the significance and applicability of these effects and relationships from laboratory measures of cognition to the live-action exhibition of perceptual athleticism.

## **Conclusions**

While much of the research within sports expertise shows smaller cueing effect differentials and interprets this as greater cognitive flexibility to overcome the unexpected outcomes, our data shows that longevity of baseball experience was actually significantly correlated with longer reaction times to temporally invalid trials in task three. The relevant theory could be that athletes become more set in their attention because they perceive it to be the most probable route of the ensuing situation and therefore have a much harder time re-orienting their attention away from their initial expectations (McAuliffe, 2004). Years of open-skill and baseball-specific experience were also significantly correlated with the degree of the phase difference in alpha-band oscillations in temporally valid task three trials within the medium SOA, while the open-skill correlation persisted throughout the long SOA too. Conclusions from these results indicate that the players with the most general open-skill experience also produced the greatest differences in alpha activity within the temporally valid trials. Future studies should isolate more controlled and specific groupings of athletic skill level and type and assess differences using differentially located cues more representative to in-game scenarios. Although, it is also possible that the tasks we designed were not complex enough to truly elicit sport-related differences in attentional control, as many suggest that the sport-skill level differences in cognition are only visible when the tasks truly encompass the unpredictability, complexity, and rapidness that is equivalent to what athletes require to become experts in their field (Mann, et.

al., 2007). Regardless of the reason behind the unanticipated behavioral and neural relationships across athletic backgrounds, the results not being quite what I expected to was even more interesting to me.

Had my study been able to include more participants and exhibit greater control over the sporting groups prior to participant recruitment, some of the near significant results would likely reach significance levels and we would also likely be able to see how these significant effects and relationships more accurately varied according to individual athletic skill-type and level of expertise. This discrepancy between the peripheral, non-informative cue types that elicited similar greater cueing effects in athletes that our central, informative cues also demonstrated would most certainly warrant more participants and greater athletic variation.

### **Acknowledgements**

While the results were not quite what I had anticipated, the process of completing and exploring this project was the most incredible experience. I cannot wait to continue my career in cognitive neuroscience research at the University of Michigan next fall, and I absolutely would not have been able to get there without Dr. Green's support and guidance. All funding for this project was courtesy of the Magellan Scholars Award and Honors College Senior Thesis Grant.

## Appendix

### Appendix 1:

#### Sporting History Questionnaire Questions

5/6/2019

Sporting History Questionnaire

#### Sporting History Questionnaire

\* Required

1. Subject # \*

---

2. Date

*Example: December 15, 2012*

#### Sporting History Questionnaire

3. Have you ever played baseball or softball?

*Mark only one oval.*

☐ Yes

☐ No *Skip to question 23.*

#### Collegiate

4. Do you currently play for the University of South Carolina NCAA team?

*Mark only one oval.*

☐ Yes

☐ No *Skip to question 11.*

#### If Yes...

5. How many years have you played baseball or softball?

---

6. At what age did you start playing?

---

7. What position(s) do you play?

---

8. How many hours a week do you practice?

---

5/6/2019

Sporting History Questionnaire

9. What place do you bat in the lineup?

---

10. What is your career batting average (if known)?

---

### Non-collegiate

11. Do you currently play baseball or softball for a non-collegiate team?

Mark only one oval.

☐ Yes

☐ No Skip to question 19.

### If Yes...

12. How many years have you played baseball or softball?

---

13. At what age did you start playing?

---

14. What position(s) do you play?

---

15. How many hours a week do you practice?

---

16. What place do you bat in the lineup?

---

17. What is your career batting average (if known)?

---

18. Which best describes your current league?

Mark only one oval.

☐ Competitive

☐ Recreational

Skip to question 23.

5/6/2019

Sporting History Questionnaire

**If you played baseball or softball previously but do not currently play, please answer the following:**

19. At what age did you start playing?

---

20. How many years did you play?

---

21. What position(s) did you play?

---

22. What level of play did you achieve? (e.g. recreational, intramural, competitive)

---

### Other Athletic History

23. Have you ever played sports other than baseball or softball?

*Mark only one oval.*

☐

Yes

☐

No     *Stop filling out this form.*

### Other Athletic History

Please fill in the sections below indicating which sports you have played, and for each one indicate if you still currently participate, the typical number of hours per week you practice the sport currently or at your peak level of play in the past, the age you started playing and approximate number of years you played the sport, and the level achieved (e.g., recreation only, collegiate, high school varsity, etc.)

24. Sport (name)

---

25. Do you currently play this sport?

*Mark only one oval.*

☐

Yes

☐

No

26. Practice (# hours per week)

---

27. Age you started playing

---

5/6/2019

Sporting History Questionnaire

**28. Number of years played**

---

**29. Level Achieved***Mark only one oval.*

- ☐ Recreation only (Incl. Intramurals)
- ☐ High School Varsity
- ☐ Collegiate Club
- ☐ NCAA
- ☐ Other: 

---

**30. Add another sport?***Mark only one oval.*

- ☐ Yes
- ☐ No *Stop filling out this form.*

**Other Athletic History**

Please fill in the sections below indicating which sports you have played, and for each one indicate if you still currently participate, the typical number of hours per week you practice the sport currently or at your peak level of play in the past, the age you started playing and approximate number of years you played the sport, and the level achieved (e.g., recreation only, collegiate, high school varsity, etc.)

**31. Sport (name)**

---

**32. Do you currently play this sport?***Mark only one oval.*

- ☐ Yes
- ☐ No

**33. Practice (# hours per week)**

---

**34. Age you started playing**

---

**35. Number of years played**

---



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